



US010080821B2

(12) **United States Patent**  
**Kangas et al.**

(10) **Patent No.:** **US 10,080,821 B2**  
(45) **Date of Patent:** **Sep. 25, 2018**

(54) **NUCLEATION OF DRUG DELIVERY  
BALLOONS TO PROVIDE IMPROVED  
CRYSTAL SIZE AND DENSITY**

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(\*) Notice: Subject to any disclaimer, the term of this  
patent is extended or adjusted under 35  
U.S.C. 154(b) by 1029 days.

(21) Appl. No.: **12/815,138**

(22) Filed: **Jun. 14, 2010**

(65) **Prior Publication Data**

US 2011/0015664 A1 Jan. 20, 2011

**Related U.S. Application Data**

(60) Provisional application No. 61/271,167, filed on Jul.  
17, 2009.

(51) **Int. Cl.**  
*A61L 29/16* (2006.01)  
*A61L 29/06* (2006.01)

(52) **U.S. Cl.**  
CPC ..... *A61L 29/16* (2013.01); *A61L 29/06*  
(2013.01); *A61L 2300/416* (2013.01); *A61L*  
*2300/606* (2013.01); *A61L 2300/622*  
(2013.01); *A61L 2300/63* (2013.01)

(58) **Field of Classification Search**  
CPC combination set(s) only.  
See application file for complete search history.

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(57) **ABSTRACT**

Drug delivery balloons have densely packed crystals of  
small particle size of the drug thereon. An amorphous drug  
coating is applied to a balloon surface and annealed to  
provide the crystals. The balloon surface is nucleated to  
induce formation of drug crystals in the annealing step to  
provide the crystals in high density with small size.

**17 Claims, 9 Drawing Sheets**

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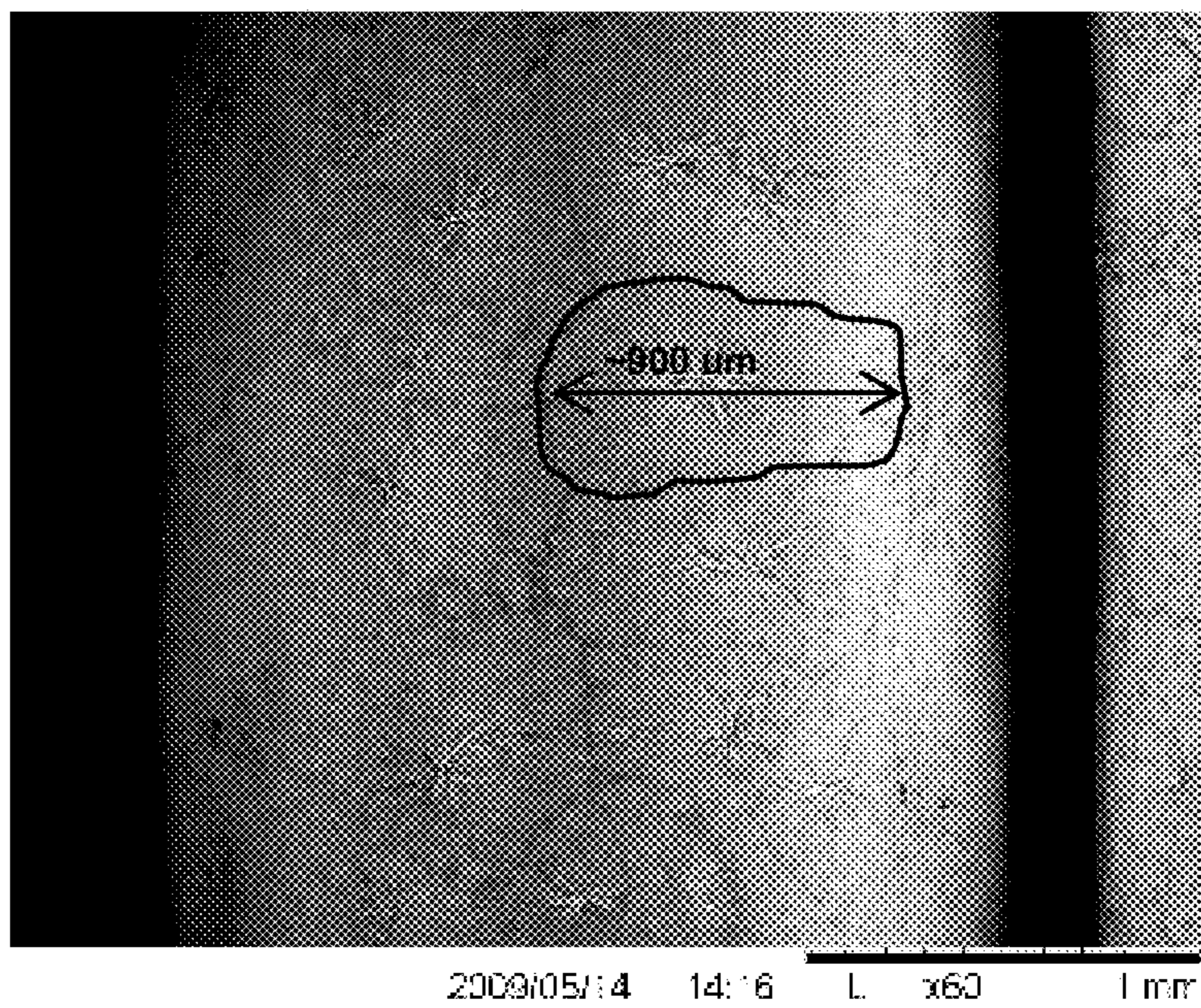
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Fig. 1



5/5 control + 15 hr VA

Fig. 2

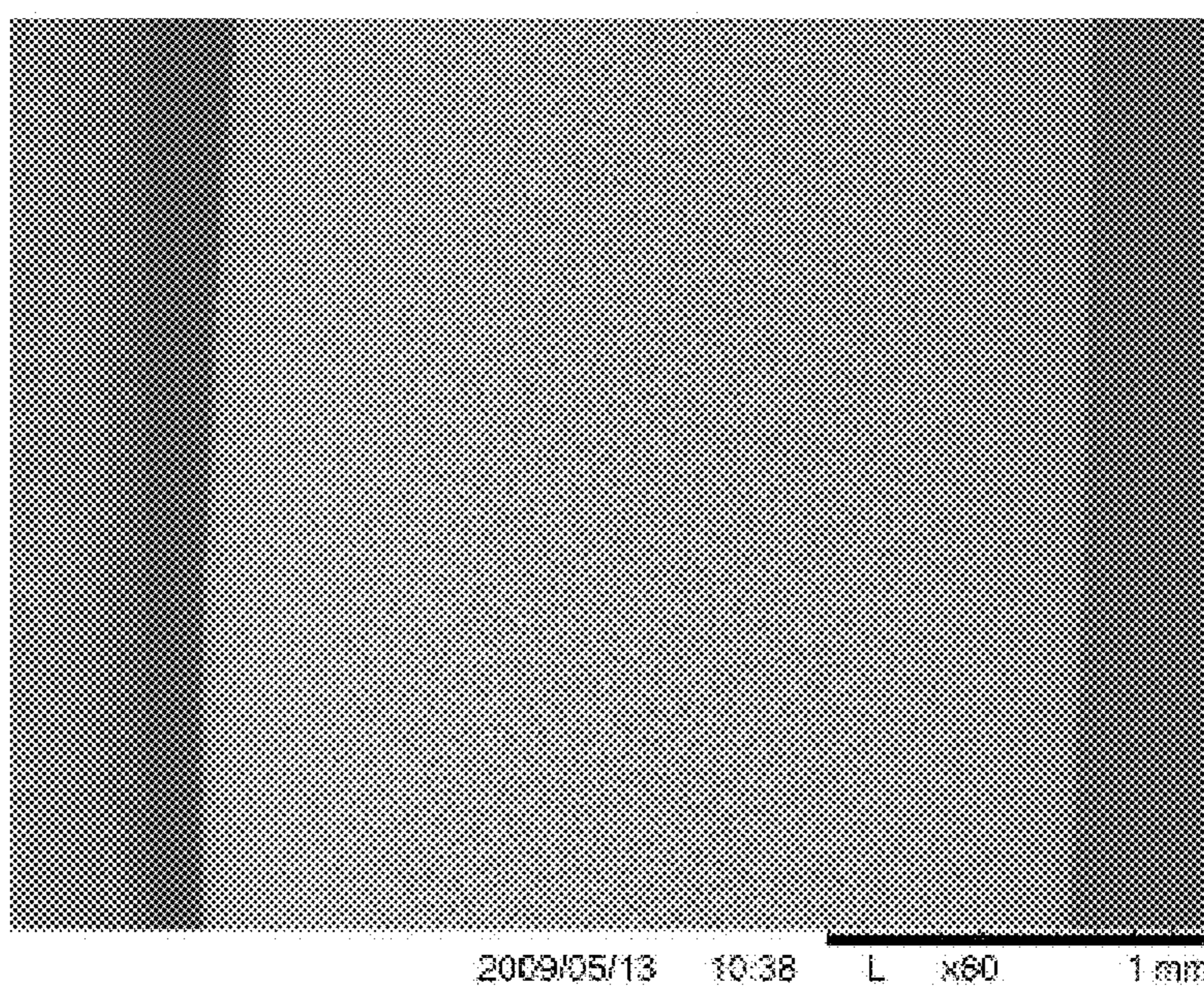




Fig. 3a

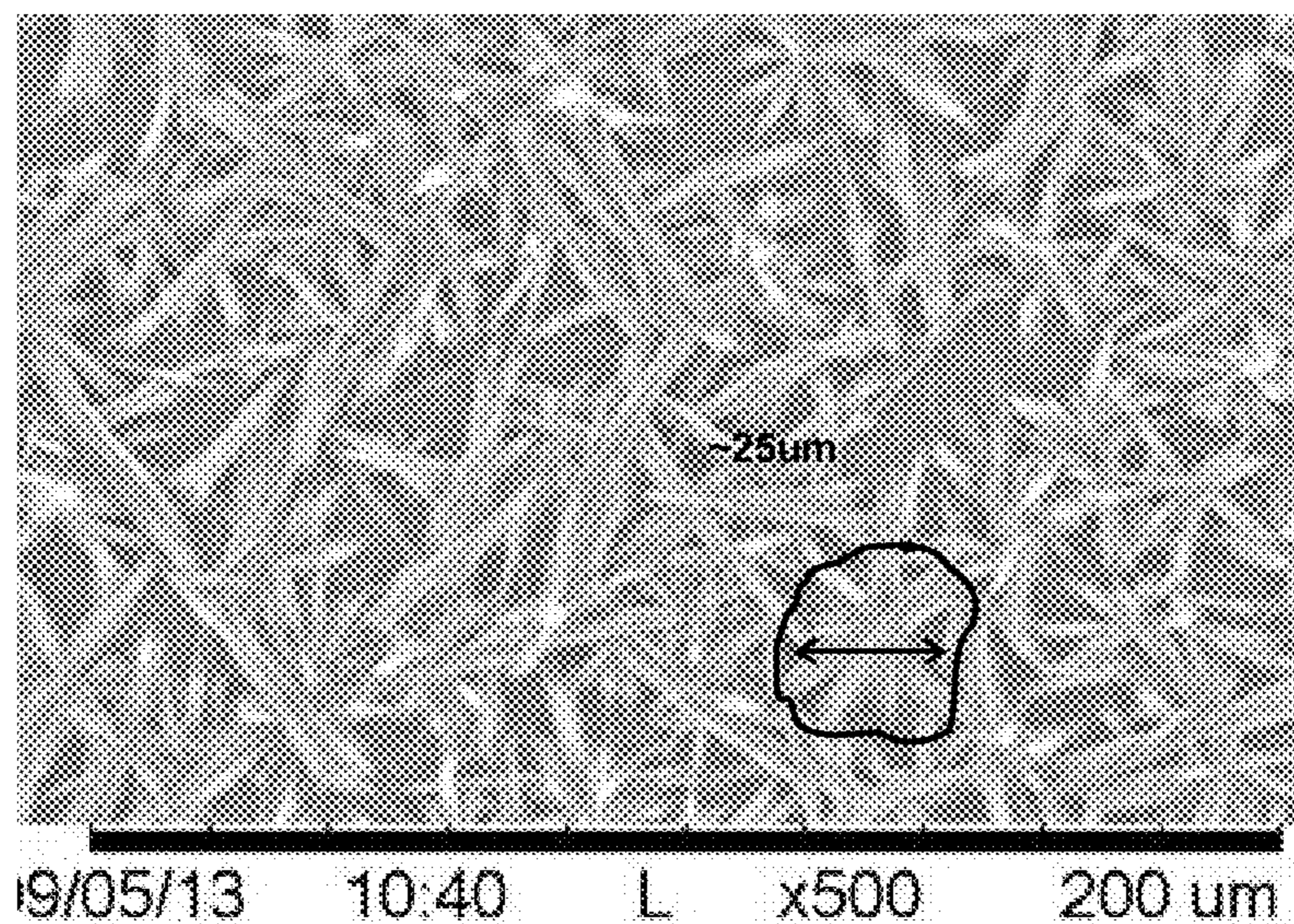


Fig. 3b

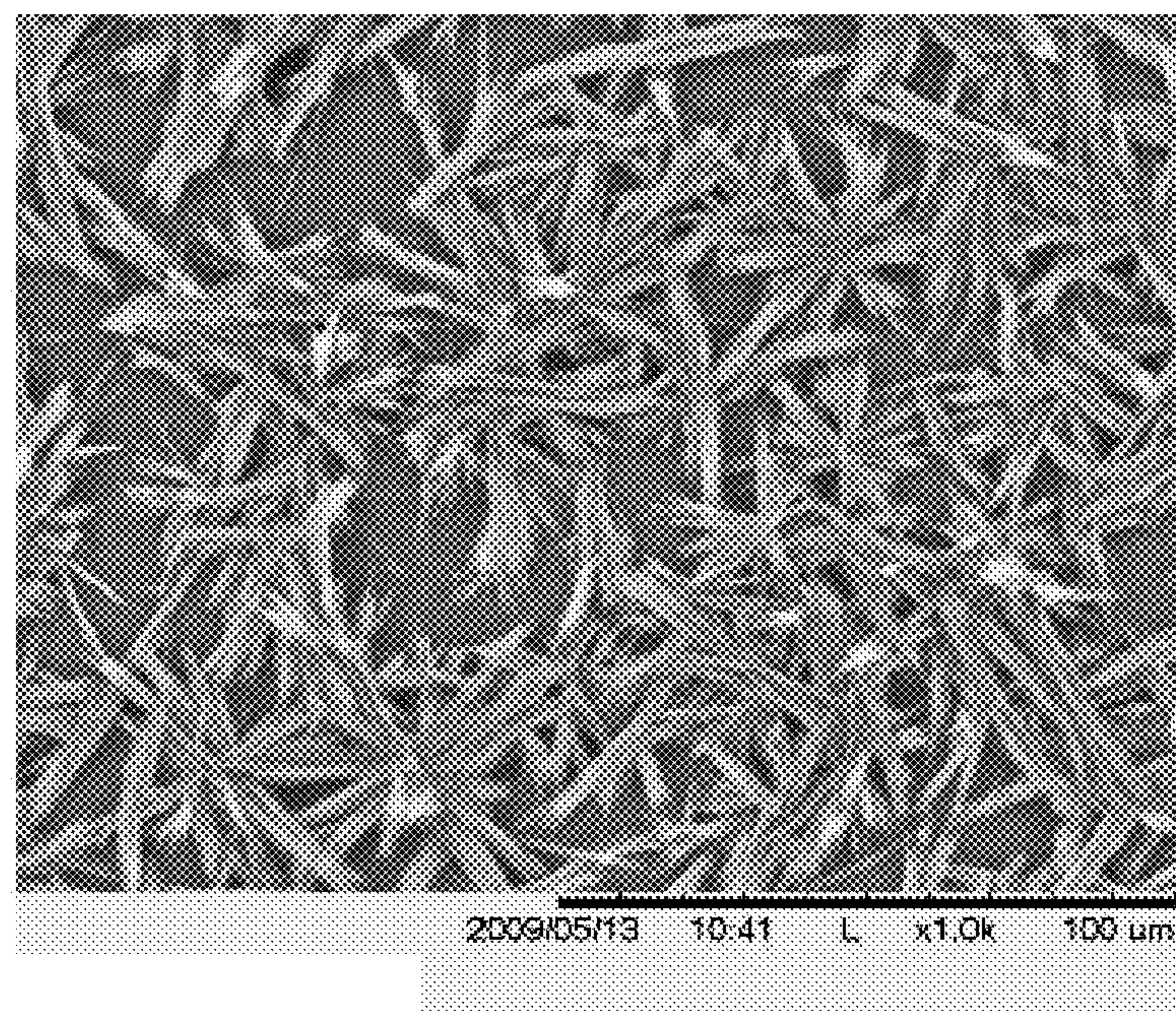


Fig. 4 Prior Art

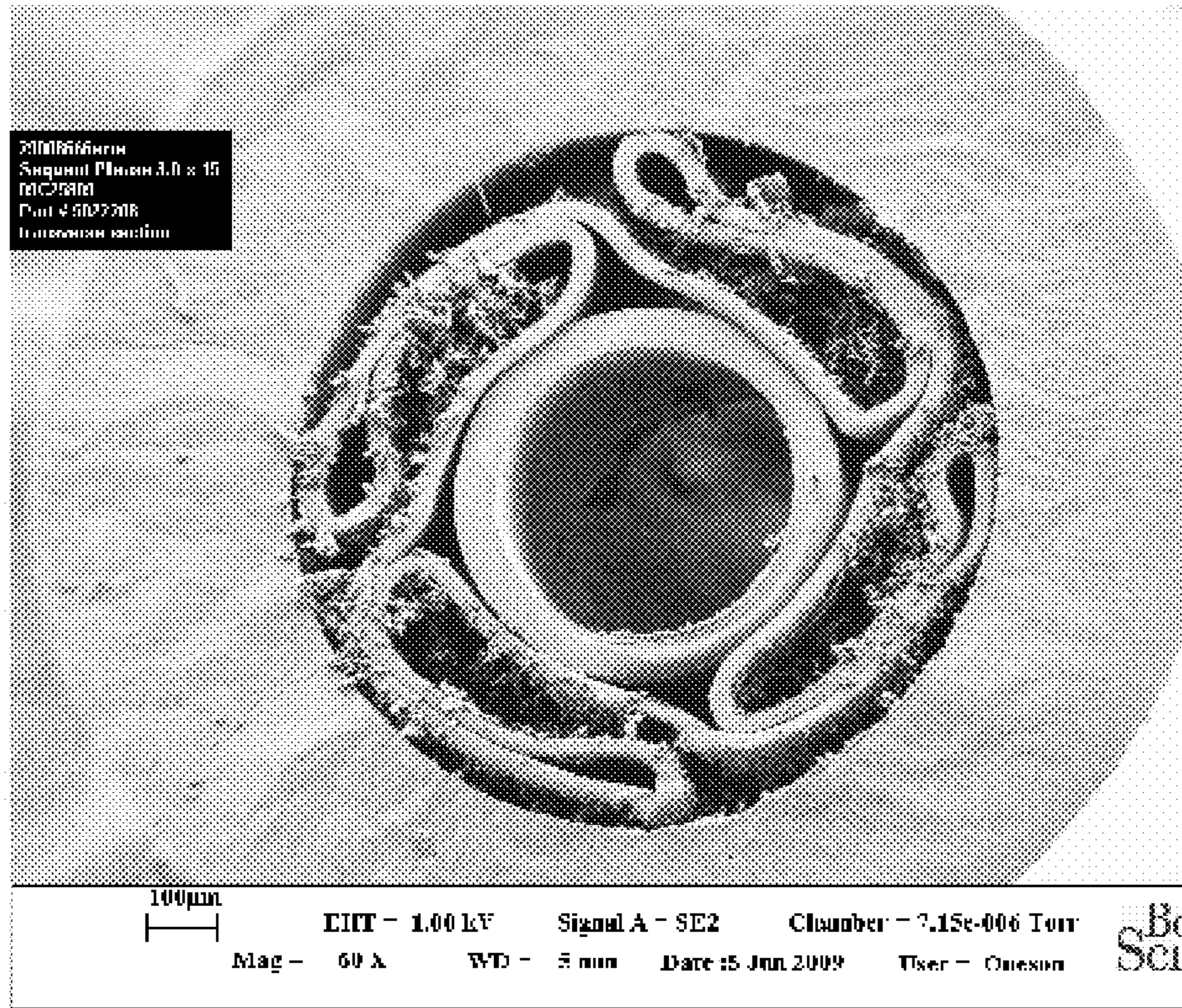


Fig. 5a

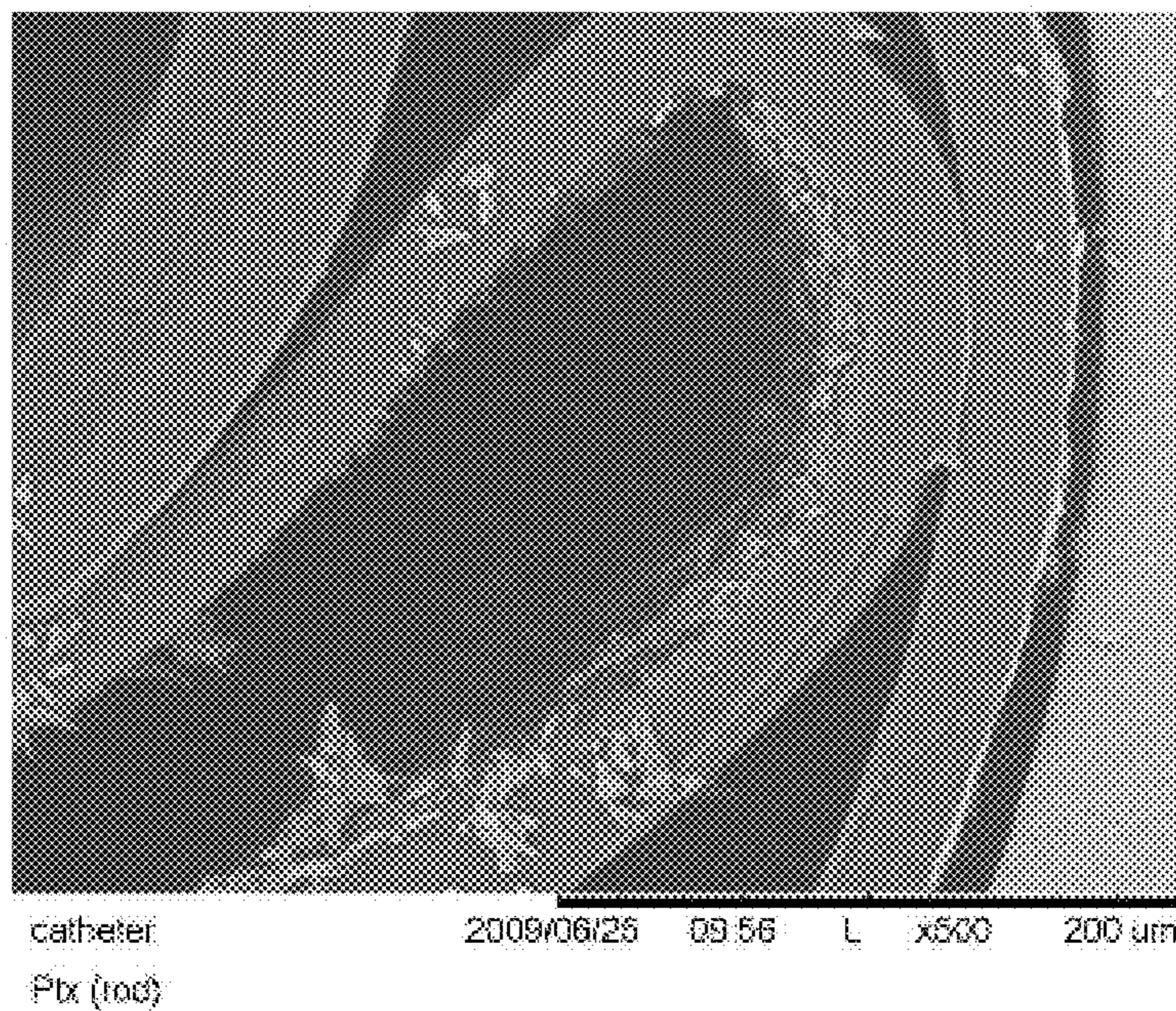
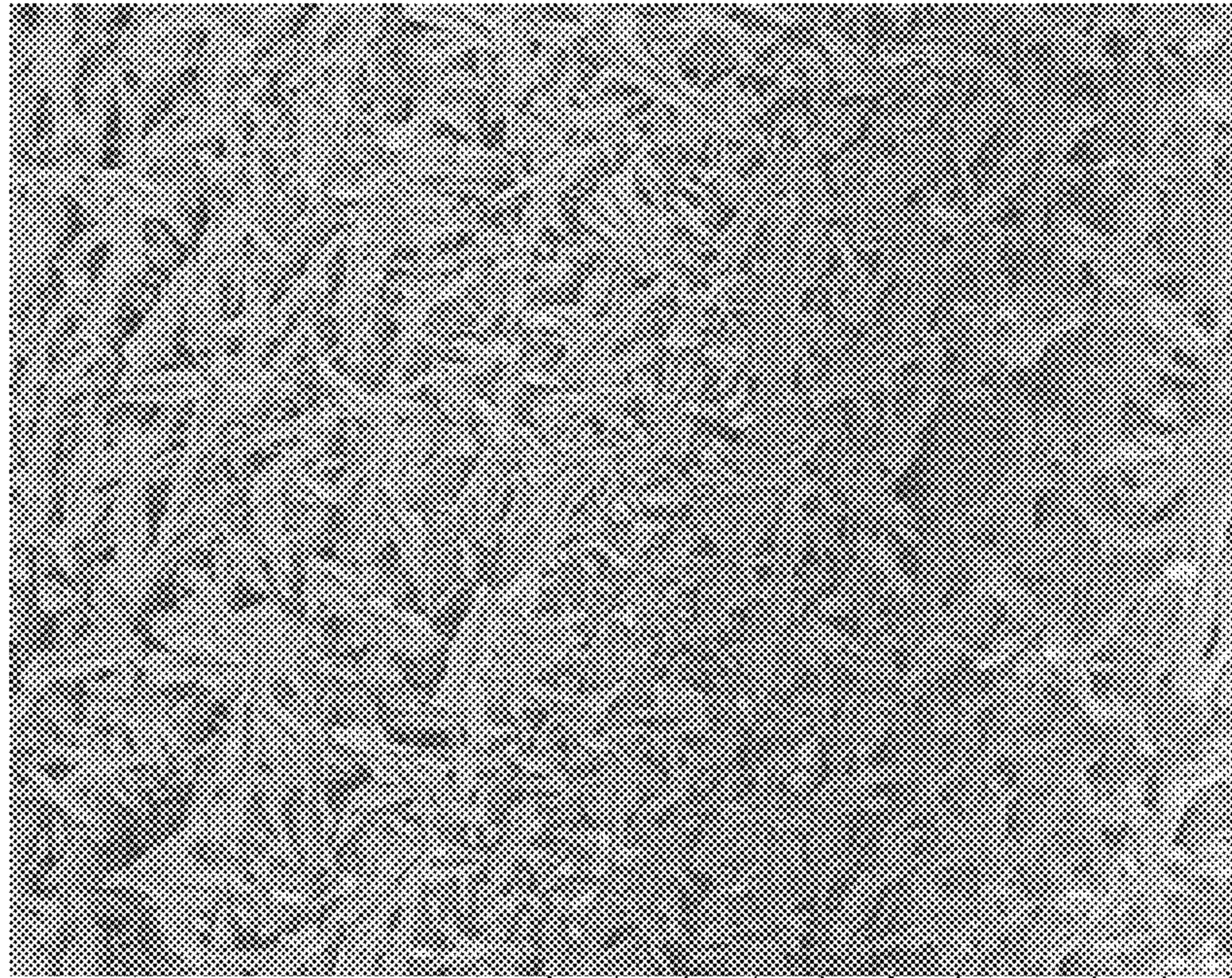
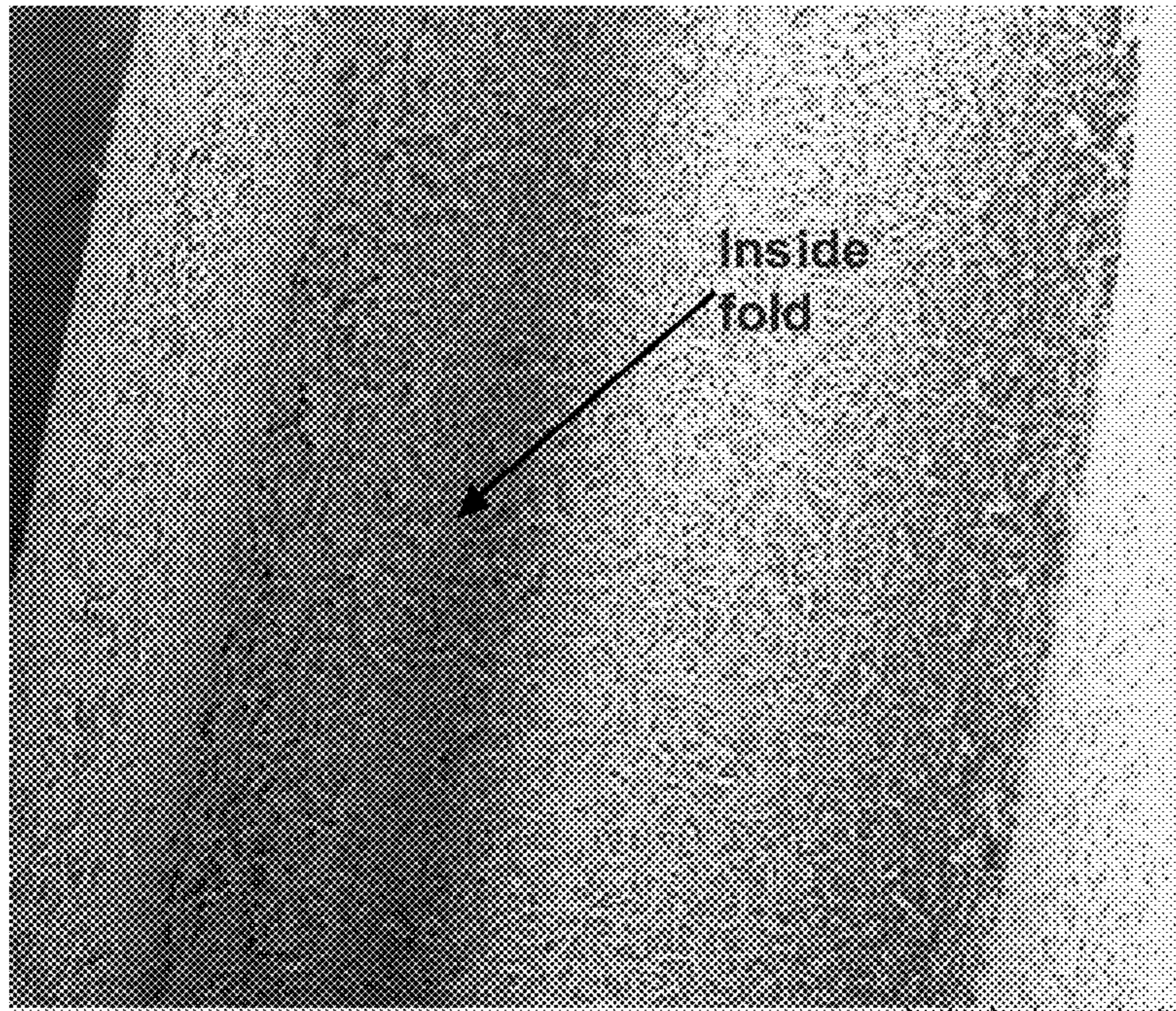


Fig. 5b



theter 2009/06/25 10:06 L x500 200 um  
x (rod)

Fig 5c



catheter 2009/06/25 10:15 L x120  
Ptx (rod)

Fig. 6a

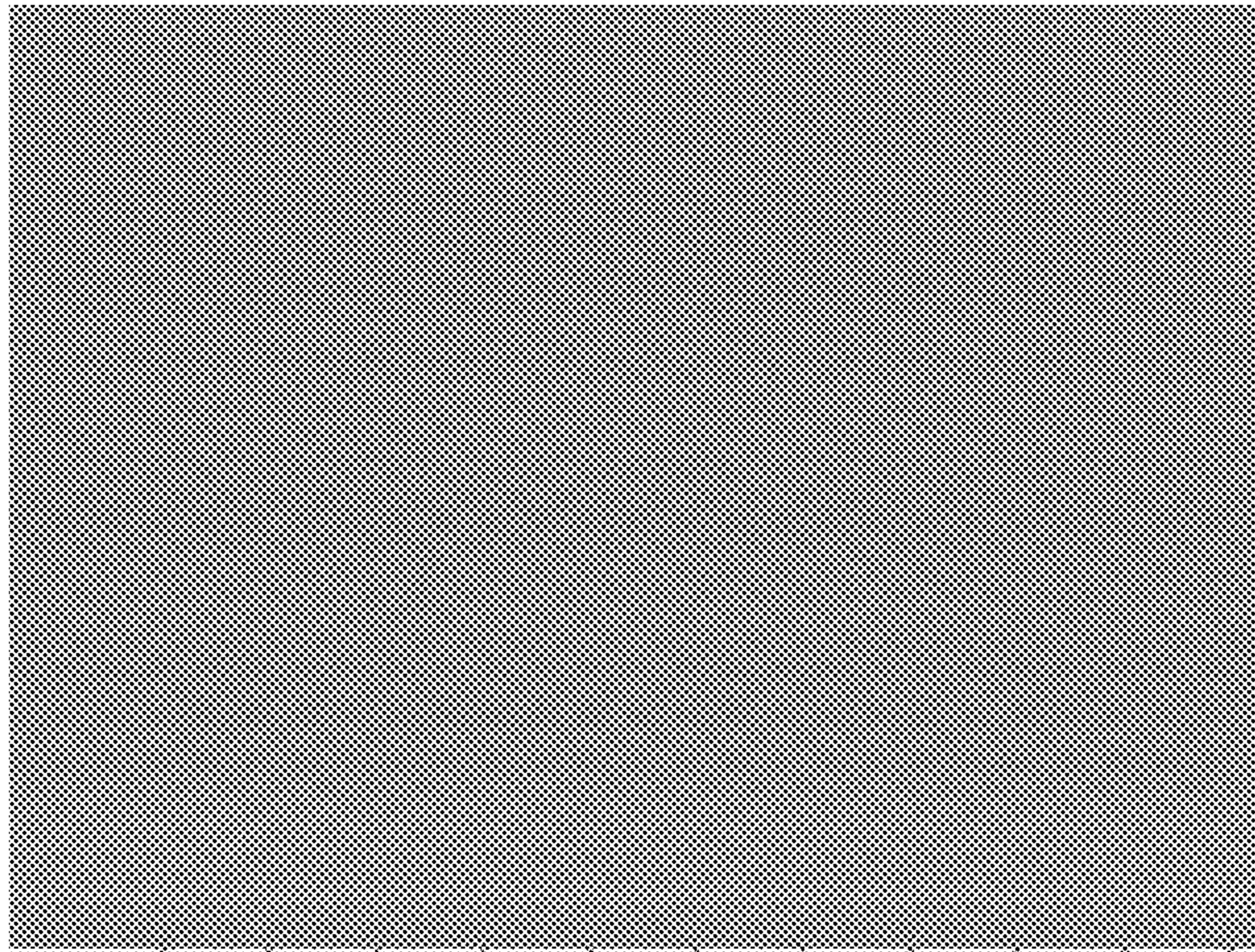


Fig. 6b

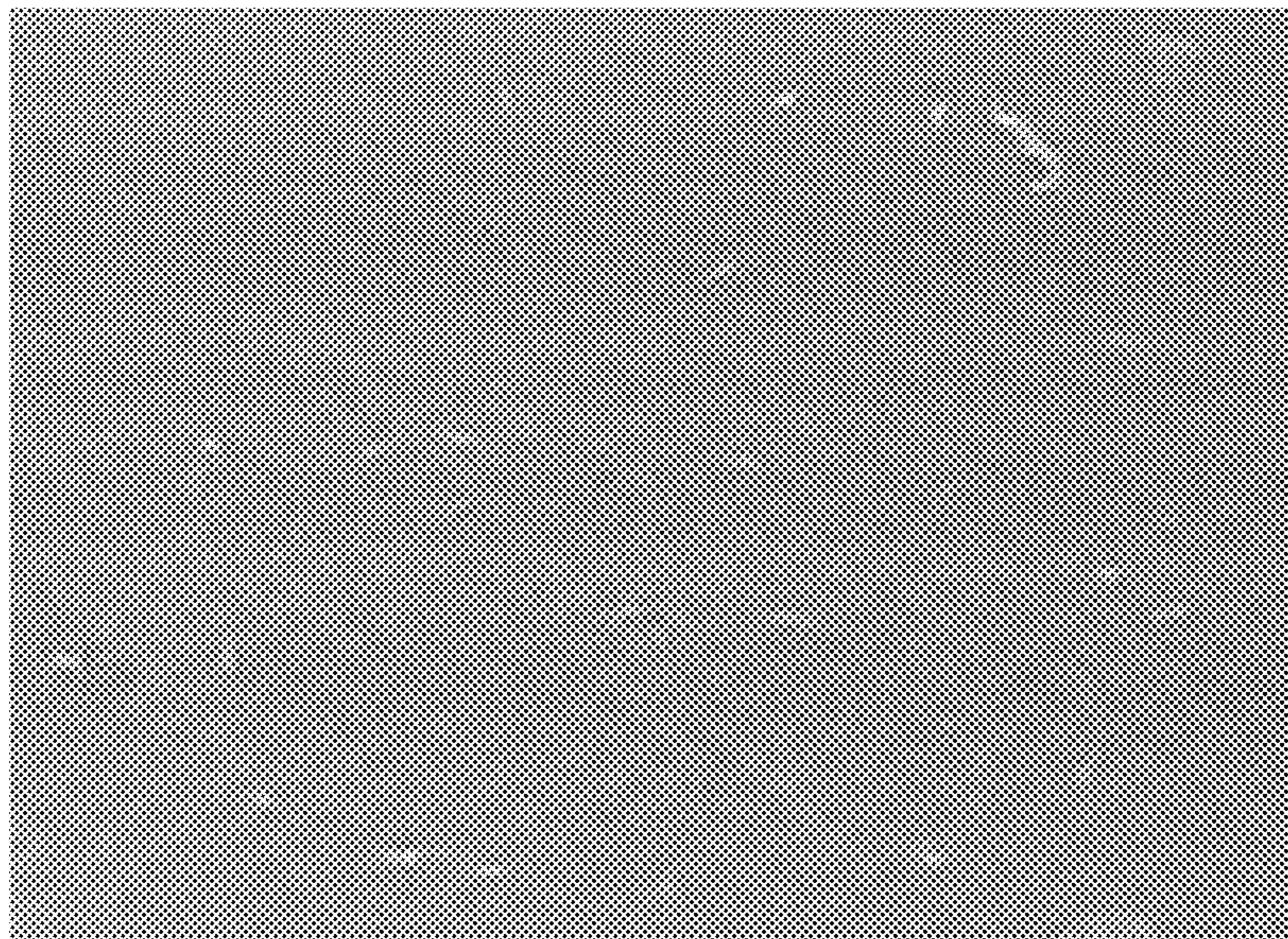


Fig. 6c

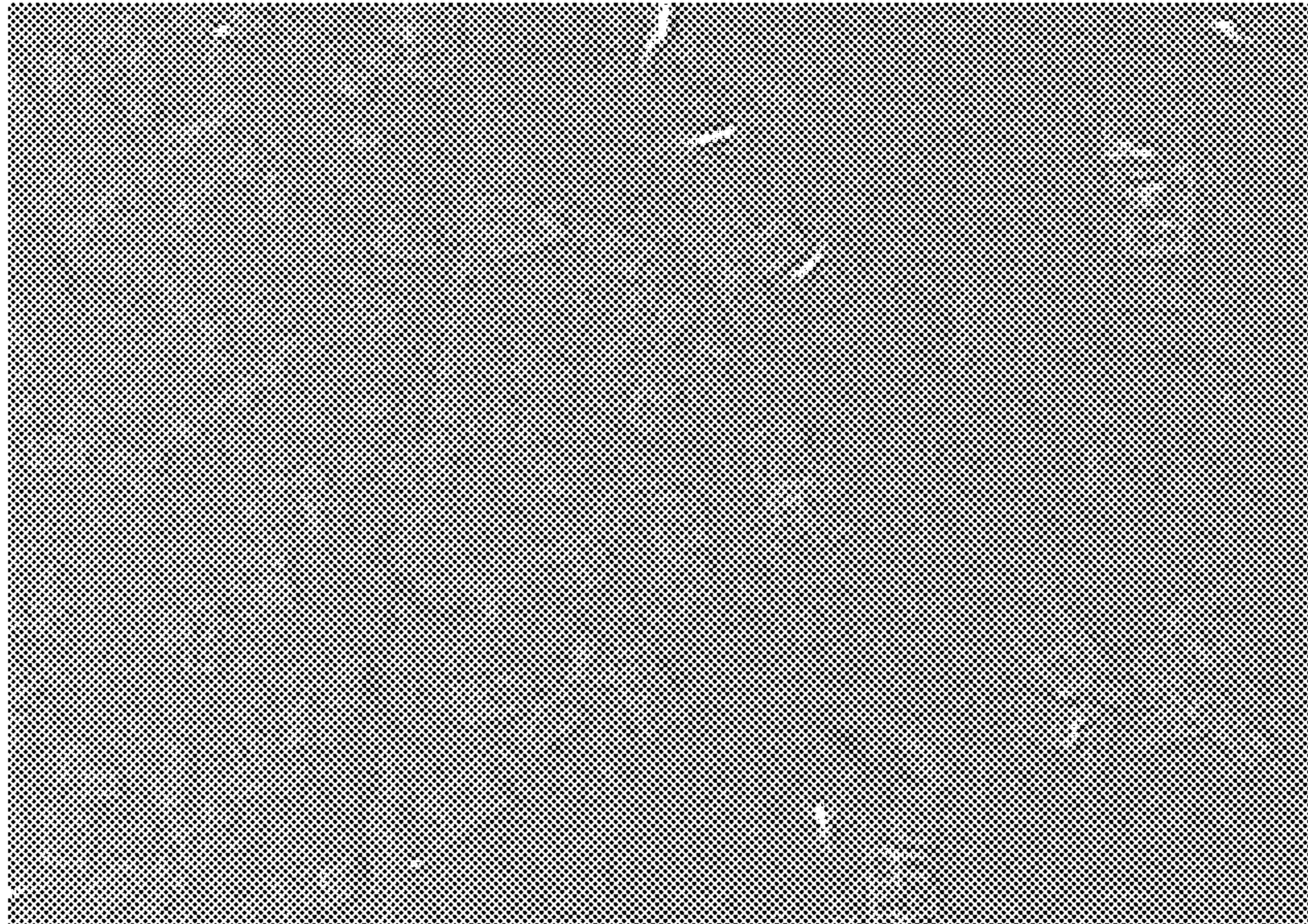


Fig. 7a

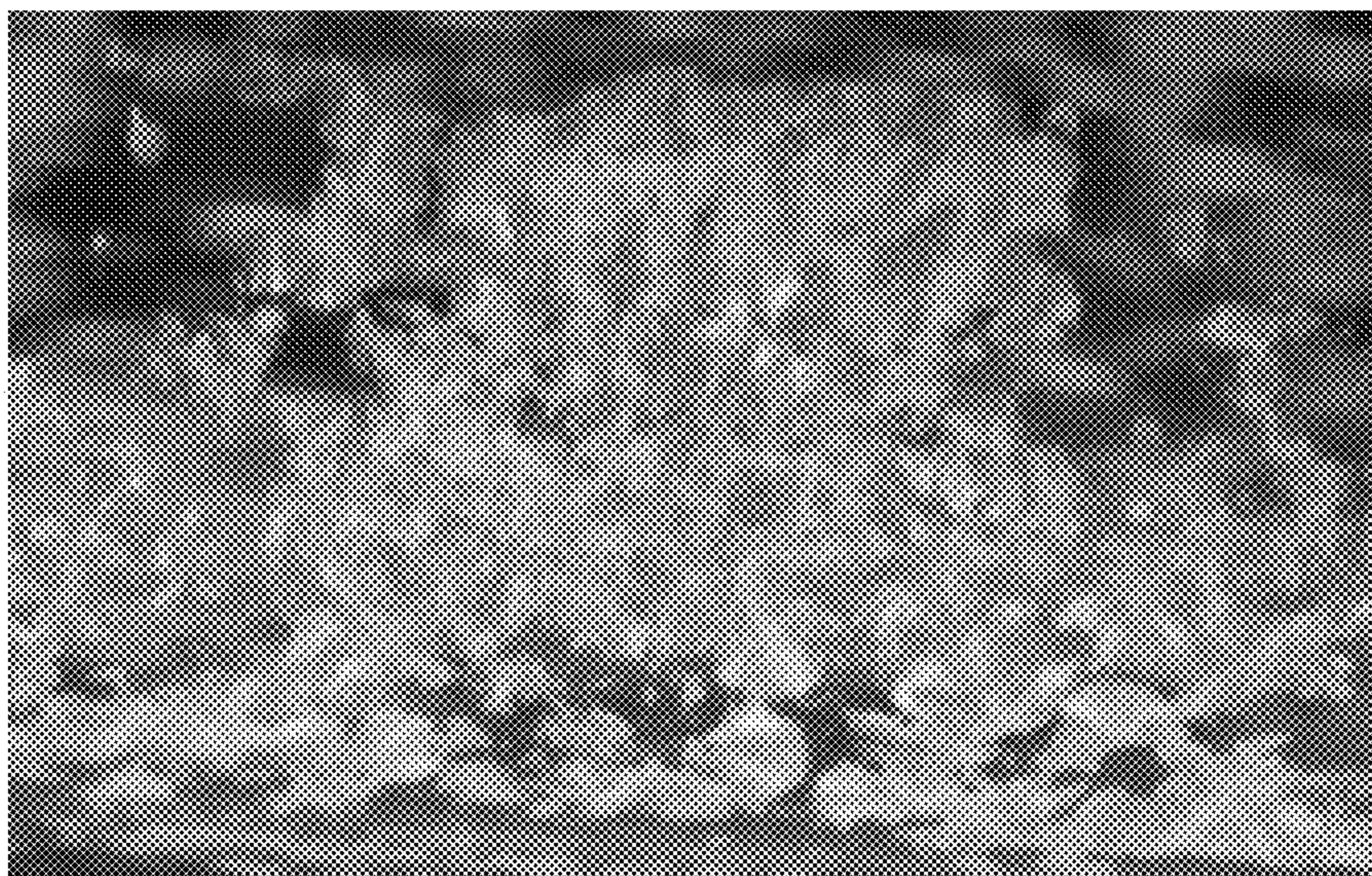


Fig. 7b



Fig. 8a

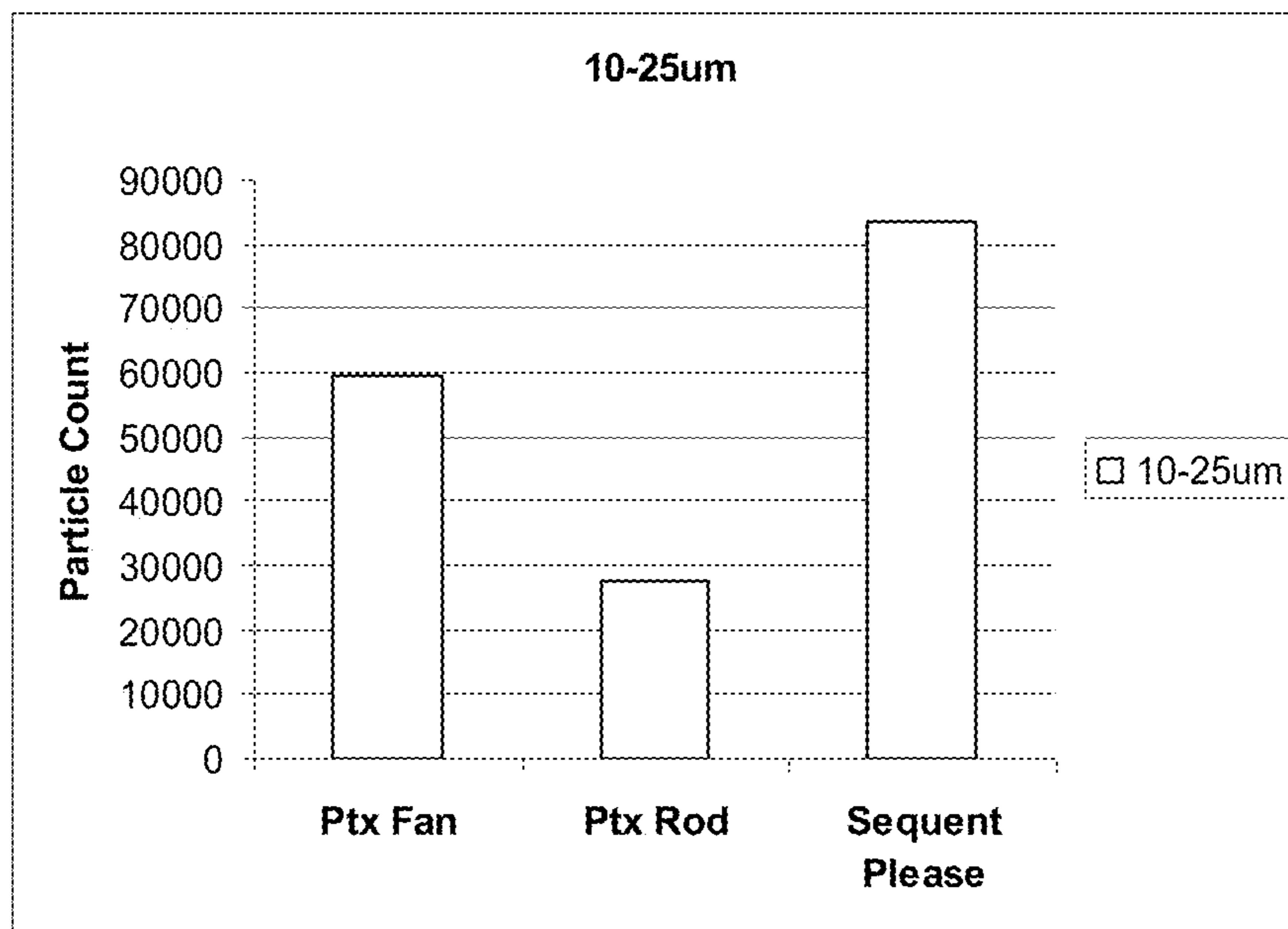


Fig 8b

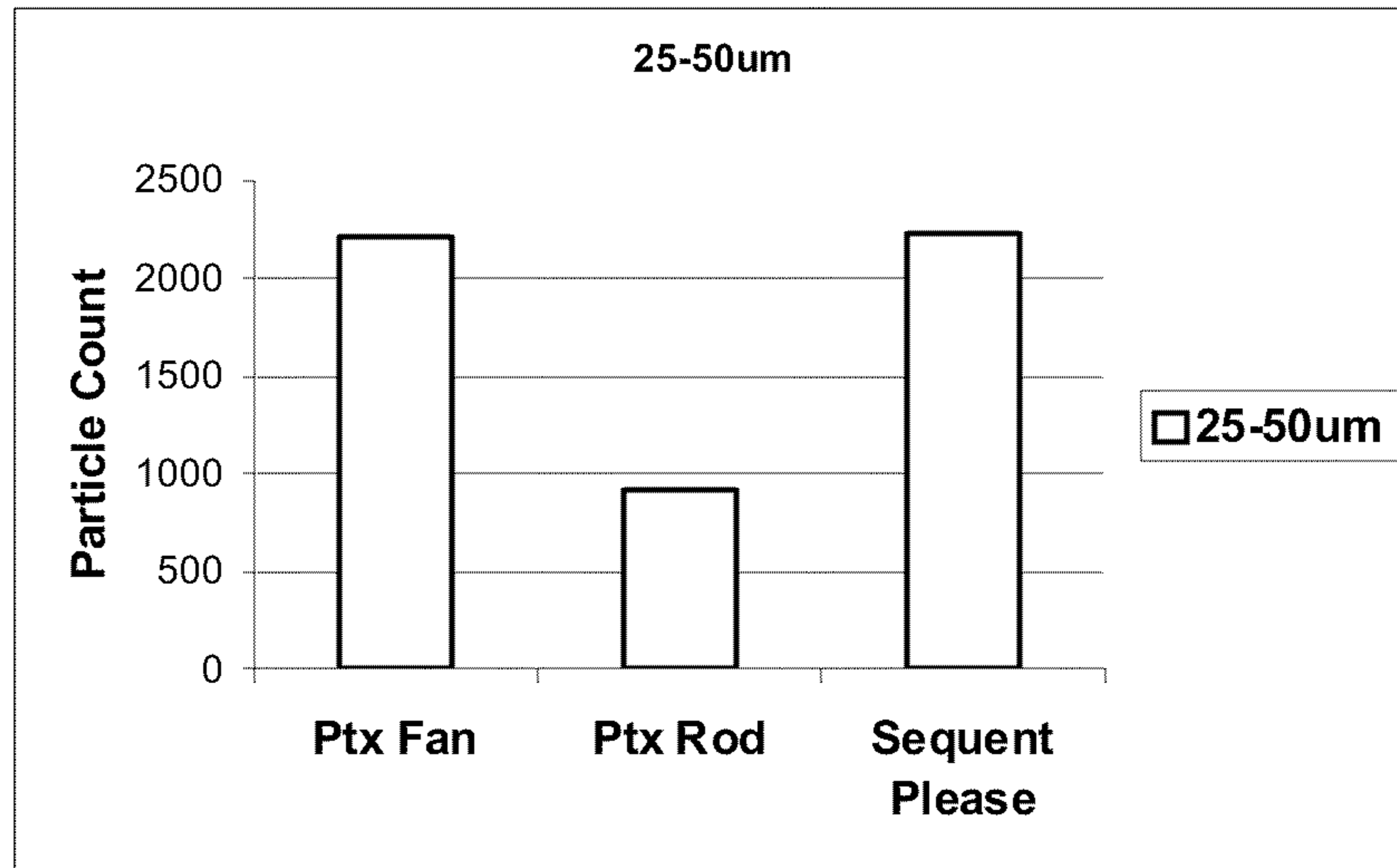


Fig. 8c

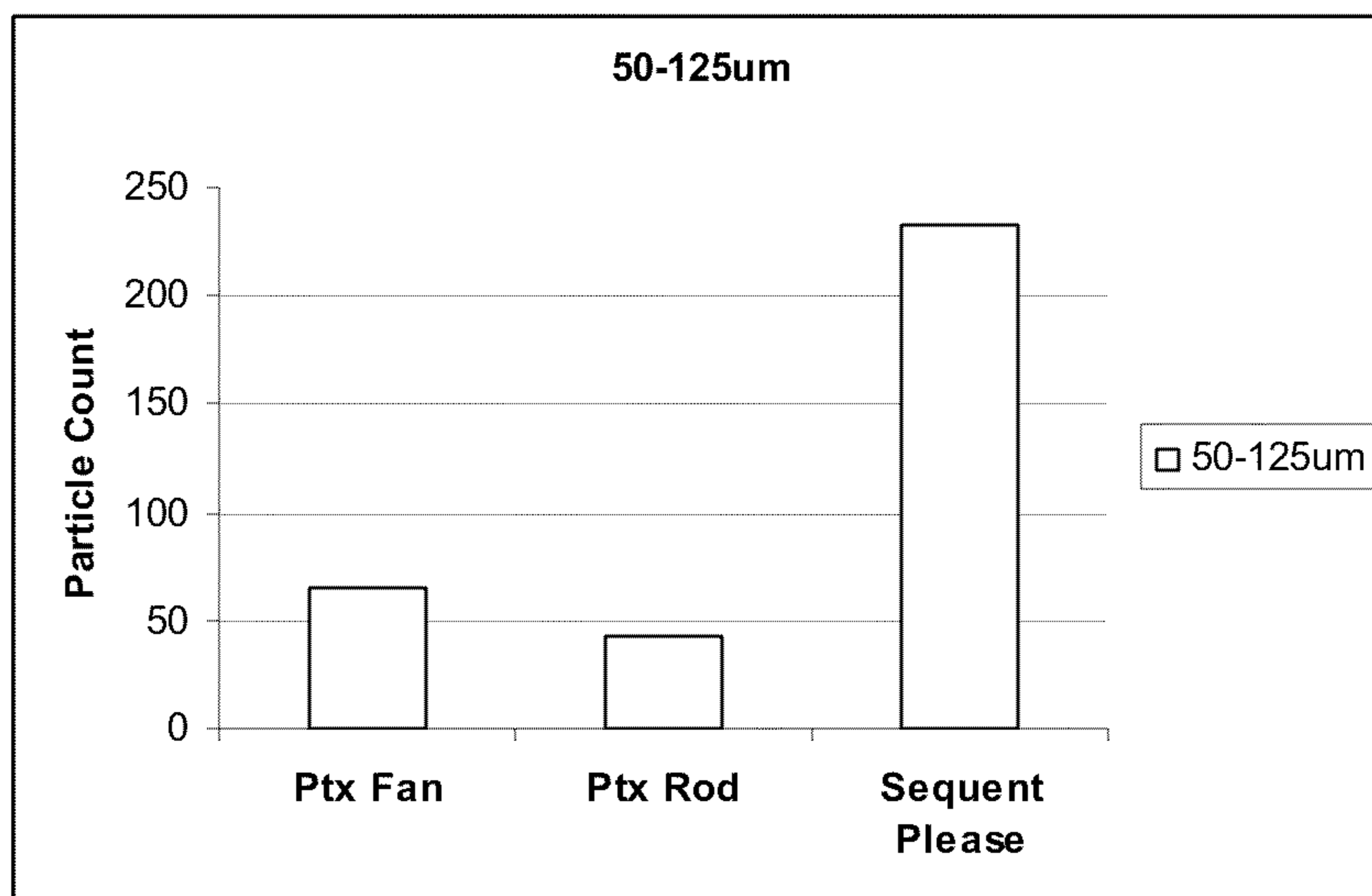
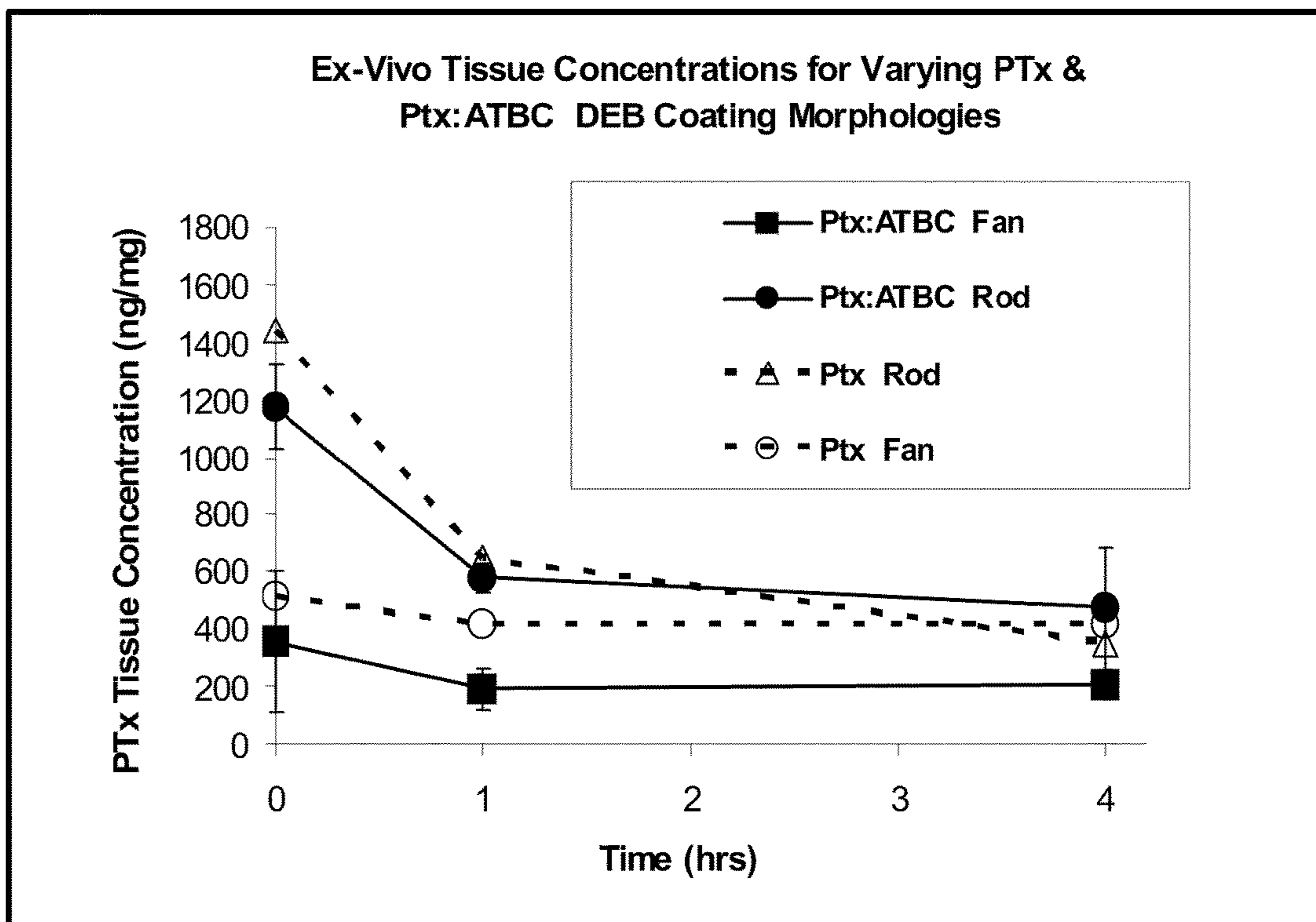


Fig. 9





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**NUCLEATION OF DRUG DELIVERY  
BALLOONS TO PROVIDE IMPROVED  
CRYSTAL SIZE AND DENSITY**

CROSS-REFERENCE TO RELATED  
APPLICATIONS

This application claims the benefit of Application No. 61/271,167, filed Jul. 17, 2009, the entire contents of which is hereby incorporated by reference.

BACKGROUND OF THE INVENTION

Balloons coated with paclitaxel containing formulations are known. In some cases paclitaxel has been applied directly to the balloon or to a coating placed on the balloon. In other cases paclitaxel has been formulated with an excipient that may be polymer, a contrast agent, a surface active agent, or other small molecules that facilitate adhesion to the balloon and/or release from the balloon upon expansion. The formulations have typically been applied from solution, and may be applied to the entire balloon or to a folded balloon, either by spraying, immersion or by pipette along the fold lines.

Paclitaxel coated balloons that provide high release rates from the balloon surface have recently been developed. However these balloons do not yet provide for delivery of predictable amounts of the drug to the tissue at the delivery site nor do they provide for a predictable therapeutic drug tissue level over an extended time period.

Earlier investigations of paclitaxel coated balloons by the applicant have shown that it is desirable to control the morphology of the drug on the balloon, that dihydrate paclitaxel crystalline form facilitates longer tissue residence time, and that the formation of crystalline paclitaxel dihydrate can be controlled by use of vapor annealing of the balloon. U.S. application 61/172,629 filed Apr. 24, 2009 describes this work in more detail and is incorporated herein by reference in its entirety.

SUMMARY OF THE INVENTION

When forming a crystalline drug on a balloon it has been found that the conditions of deposition of the drug on the balloon can be influenced to produce drug crystals on a balloon of high density and small size that provide improved delivery characteristics.

In one aspect the invention describes a method of forming a drug delivery balloon that provides nucleation sites on the balloon to control the crystalline particle size of paclitaxel or another drug. Control of particle size influence transfer and dissolution of the drug. Other aspects of the invention relation to balloons that may be produced by such methods.

In some embodiments the invention pertains to a method of making a drug delivery balloon having a coating thereon comprising a drug, wherein the drug has characteristic amorphous and crystalline forms comprising:

- a) applying a coating of the drug in amorphous form, and
- b) annealing the coated balloon to produce a crystalline form of the drug in situ on the balloon,

wherein in the applying step a) the drug coating is applied to a balloon surface that has been nucleated to induce formation of drug crystals in the annealing step. Various techniques of nucleating the balloon are described, including particular embodiments involving vapor pretreatment of the balloon to induce blooming of a component of the balloon material as a nucleating agent.

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In other embodiments the invention pertains to a drug delivery balloon comprising a layer of crystalline drug particles of average length less than 100  $\mu\text{m}$  length substantially uniformly distributed over the balloon; or to a drug delivery balloon comprising a layer of crystalline drug particles of less than 100  $\mu\text{m}$  average length densely packed on at least a portion of the surface of the balloon.

Still other aspects of the invention are described in the Figures, the Detailed Description of Preferred Embodiments and/or in the Claims below.

BRIEF DESCRIPTION OF THE FIGURES

FIG. 1 is a magnified image showing crystal size of paclitaxel/PVP coated on an untreated balloon and crystallized by vapor annealing.

FIG. 2 is a magnified image showing a balloon made in accordance with one aspect of the invention.

FIG. 3a is an SEM image of a portion of the balloon surface of the balloon of FIG. 2.

FIG. 3b is a higher resolution image of a coating similar to FIG. 3a.

FIG. 4 is an SEM image of a cross-section of a commercial prior art Sequent Please™ catheter taken through the folded balloon.

FIG. 5a is a cross-sectioned fold region of a balloon made in accordance with one aspect of the invention.

FIG. 5b is surface region of a balloon as in FIG. 5a.

FIG. 5c is surface region of a balloon surface region made in accordance with one aspect of the invention at a lower magnification than FIG. 5b.

FIGS. 6a-6c are SEM images of Pebax® balloon surfaces after vapor pre-annealing for different time intervals.

FIGS. 7a and 7b, respectively, are images of drug deployed in tubing from balloons with fan-like and rod-morphologies, as described in Example 2.

FIGS. 8a-8c are graphs the results of particle counts for various size ranges obtained in a flowing system experiment described in Example 3.

FIG. 9 is a graph of results of ex-vivo tissue concentrations found in a tissue deployment model experiment described in Example 4.

DETAILED DESCRIPTION OF PREFERRED  
EMBODIMENTS

Drugs such as paclitaxel ("Ptx") are suitably delivered from a drug delivery balloon in a crystalline form, or substantially in crystalline form in order to maximize tissue residence time at the delivery site. The coating however must be sufficiently coherent to allow for tracking to the treatment site and yet readily loose adherence to the balloon upon expansion of the balloon. In the flowing system it is also desirable that delivery to the tissue site be maximized, systemic loss (non-localized delivery) be minimized and that the material lost systemically have minimal size for safety reasons. In particular it is desirable to minimize particle size to reduce the risk of particles lost from the coated balloon lodging in the patient's vascular capillary system. Further, the size, distribution and crystallinity of the drug particles play a critical role in tissue uptake and duration. Methods to control these factors are important in designing drug delivery balloons.

According to some embodiments of the invention the drug is one that has crystalline and amorphous forms, and is desirably delivered in a crystal form. The drugs which can be used in embodiments of the present invention, can be any

therapeutic agent or substance that has therapeutic benefit for local administration by delivery from a medical device inserted into the body and that also exists in such polymorph forms. In this aspect the drug is coated on the balloon, with or without an excipient, in an amorphous form and then is converted to the desired crystalline form in an annealing step that grows the crystalline drug in the coating in-situ on the surface that more closely approximate the desired properties of a drug delivery balloon.

In some embodiments the drug is a lipophilic substantially water insoluble drug, such as paclitaxel or another drug that inhibits restenosis, for instance paclitaxel analogous and derivatives, rapamycin rapamycin analogous and derivatives, everolimus, everolimus analogous and derivatives, and mixtures thereof. Other drugs that may be suitable are described in documents identified later herein. Mixtures of drugs, for instance paclitaxel and rapamycin, or their analogs or derivatives may be employed. The drug is suitably one that is able to form a crystalline form by treatment with a solvent or solvent vapor after it is applied to the balloon.

Some embodiments further involve applying the amorphous drug coating to a balloon that has been nucleated to induce crystallization during the annealing step. Nucleation of the balloon may be provided by providing the balloon surface with a specific texturization, by pretreating the balloon with a nucleating agent effective for inducing crystallization of the specific drug, by inducing migration to the balloon surface (blooming) of a component of the balloon substrate that functions as a nucleating agent, or by utilizing a material for the drug delivery balloon for which such blooming occurs intrinsically under the processing conditions of balloon formation, aging or drug coating processing.

In some embodiments the drug is formulated with an excipient. An excipient is an additive to a drug-containing layer that facilitates adhesion to the balloon and/or release from the balloon upon expansion. The excipient may be polymer, a contrast agent, a surface active agent, or other small molecule. In at least some embodiments the drug is substantially insoluble in the excipient.

In some embodiments the excipient may remain on the delivery device at the time of drug transfer but allow efficient transfer of the drug from the mixture. In some embodiments the excipient provides weak phase boundaries with the drug particles that are easily overcome when a balloon is expanded, regardless of whether the excipient remains on the device or initially leaves the device with the drug. In some embodiments the excipient substantially degrades or dissolves in the course of the deployment or during transfer of the drug from the device at the site of administration such that little or none of the excipient is detectable on the tissue after a short interval, for instance an interval of 2 days, 1 day, 12 hours, 4 hours, 1 hour, 30 minutes, 10 minutes or 1 minute. In some embodiments dissolution or degradation of the excipient during deployment provides porosities in the drug-containing layer by the time the device is at the site of administration.

Examples of excipients that may be employed include polymeric and non-polymeric additive compounds, including polyvinylpyrrolidone (PVP), sugars such as mannitol, contrast agents such as iopromide, citrate esters such as acetyltributyl citrate, glycerol esters of short chain (i.e. C<sub>2</sub>-C<sub>8</sub>) mono-carboxylic acids such as triacetin, and pharmaceutically acceptable salts.

In some embodiments the drug is applied to a device, such as a balloon, that provides transient contact delivery of the drug directly to tissue, without use of a release regulating

polymer such as is typically present on drug eluting stents or in microencapsulated drug particles.

In some embodiments the drug may be coated with a protective polymeric layer that functions to reduce loss during deployment of the device to the site of administration, but that substantially disintegrates in the course of the deployment or during transfer of the drug from the device at the site of administration. Suitably such protective layer has a thickness of 0.5 μm or less, 0.1 μm or less, or 0.01 μm or less. Polymers or copolymers that have a good solubility in water and a molecular weight sufficient to slow dissolution of the coating enough to provide practical protection may be used. Other protective layers may be effective if they break up into fine particles during drug delivery, for instance upon balloon expansion. Protective coating thickness may be adjusted to give an acceptable dissolution and/or degradation profile.

In some embodiments the drug containing layer is applied over an underlayer of material that has a high solubility in bodily fluids to undercut the drug facilitate breakup of the drug-containing layer upon balloon expansion. An example of a suitable underlayer material is pectin.

Numerous other excipients and additive compounds, protective polymer layers, underlayer materials and drugs are described in one or more of the following documents:

U.S. Pat. No. 5,102,402, Dror et al (Medtronic, Inc.)

U.S. Pat. No. 5,370,614, Amundson et al, (Medtronic, Inc.)

U.S. Pat. No. 5,954,706, Sahatjian (Boston Scientific Corp)

WO 00/32267, SciMed Life Systems; St Elizabeth's Medical Center (Palasis et al)

WO 00/45744, SciMed Life Systems (Yang et al)

R. Charles, et al, "Ceramide-Coated Balloon Catheters Limit Neointimal Hyperplasia After Stretch Injury in Carotid Arteries," *Circ. Res.* 2000; 87; 282-288

U.S. Pat. No. 6,306,166, Barry et al, (SciMed Life Systems, Inc.)

US 2004/0073284, Bates et al (Cook, Inc; MED Inst, Inc.)

US 2006/0020243, Speck

WO 2008/003298 Hemoteq AG, (Hoffman et al)

WO 2008/086794 Hemoteq AG, (Hoffman et al)

US 2008/0118544, Wang

US 20080255509, Wang (Lutonix)

US 20080255510, Wang (Lutonix)

All incorporated herein by reference in their entirety.

According to an embodiment the invention the drug is provided on the device in a manner that is controlled to produce a predetermined ratio of said morphological forms.

In some cases of drug delivery balloons described previously, paclitaxel has been applied directly to the balloon or to a coating placed on the balloon. In other cases paclitaxel has been formulated with an excipient that may be polymer, a contrast agent, a surface active agent, or other small molecules that facilitate adhesion to the balloon and/or release from the balloon upon expansion. The formulations have typically been applied from solution, and may be applied to the entire balloon or to a folded balloon, either by spraying, immersion or by pipette along the fold lines.

It has been found that subjecting some polyamide block copolymer balloons (e.g. balloons made of Pebax® polymers such as Pebax® 6333, 7033, 7233), to ethanol vapor causes lauryl lactam (residual monomer, dimers and trimers) present in Pebax® polymer) to crystallize at the surface of the balloon. This is shown in FIGS. 6a-6c described below. The lauryl lactam can be seen as small rod-like crystals in FIG. 6b and square crystals observed at longer annealing

times (FIG. 6c). It has been discovered that the lauryl lactam crystals can act as a nucleating agent for paclitaxel crystallization. The presence of lauryl lactam crystals provide nucleation sites and thus increased number and hence smaller crystals. The number and size of the crystals can be controlled by controlling the pre-vapor annealing time.

Taking advantage of the built-in nucleation agent present in Pebax® polymers provides a convenient way of controlling paclitaxel crystal size but the invention is not limited to lauryl lactam as nucleating agent. Other nucleating agents (particles) could be added to the dip-coating solution or applied in a pre-coat. In this way one could precisely control the concentration of nucleating agent. Potential nucleating agents are organic or inorganic crystalline water soluble compounds that already find use as drug excipients such as sodium carbonate, sodium citrate, sodium chloride, sugars, etc, that have low solubility in the solvent used to apply the drug coating. For a lipophilic drug such as paclitaxel suitable nucleating agents are likely organic compounds. In some embodiments the nucleating agent is a compound listed on the FDA database of inactive ingredients. The nucleating agent compounds are desirably insoluble in the dip-coating solvents so that they survive the drug application step in particulate form and thus can be coated as particulates at very low concentrations (ng to µg). Water soluble compounds are desirable so that upon deployment of the balloon, they would dissolve in the blood.

In some embodiments the particulate nucleating agent, whether added to the surface or produced by blooming, or otherwise is provided on the substrate, before application of the drug coating at a density of from about 10 particle/mm<sup>2</sup> to about 5000 particles/mm<sup>2</sup>, or from about 100 particles/mm<sup>2</sup> to about 2000 particles/mm<sup>2</sup>. The size of the particulate nucleating agent may vary. In some embodiments the particulate nucleating agent has its major dimension in the size range of from about 10 nm to about 20 µm, or from about 100 nm to about 10 µm.

Another potential method to create nucleation sites is to texture the balloon surface with micrometer (µm) or nanometer (nm) scale features that may act as nucleation sites. It is known in the field of organic chemistry that in purification of organic compounds via crystallization from solution that using a glass vessel that has scratches on the interior walls can act as nucleation sites for crystallization. The balloon surface could be textured in a number of ways such as using a textured balloon mold or by texturing via laser.

In some embodiments, the rate at which the solvent evaporates within the chamber and the time in which the balloon resides in the container may be important to durability of the drug coating microstructure. For example when an amount of solvent is added to the base of the a vapor annealing chamber in a small Petri dish and the balloon catheter is held in the chamber for 4 hours the coating has been observed to have improved durability to resist delamination while being manipulated in subsequent folding and balloon protector application steps compared to balloons that were added to the annealing chamber after it has first been saturated ethanol vapor from a larger surface to volume source that resulted from covering the bottom of the annealing chamber with ethanol. In some embodiments the volume to surface ratio (ml/cm<sup>2</sup>) may be about 35-about 75 for instance about 45-55.

Vapor annealing time for forming the crystalline drug on the balloon may range widely, for instance from about 5 minutes to about 24 hours, or even longer. A typical time may be at least 30 minutes up to about 16 hours. The solvent

suitably is one that induces crystallization of the drug without attacking the balloon. In some embodiments an alcohol solvent is employed, for instance a C<sub>1</sub>-C<sub>4</sub> alcohol.

After the vapor annealing step the balloon catheter may be dried in a vacuum oven or by exposure to ambient conditions. In some embodiments a vacuum drying step may also contribute to improvement of coating durability as compared to ambient drying conditions.

The following non-limiting examples illustrate aspects of the invention and of the prior art.

#### Example 1. Dip Coat and Anneal Processes

##### (a) Fan-Like Crystal Morphology

A 20% solution of paclitaxel/PVP (55K MW) (95/5 wt/wt) in 95/5 (wt/wt) THF/IPA is prepared. A Quantum Maverick balloon (3.0 mm dia.×16 mm length, Pebax® 7233) is coated in the inflated condition by dipping into the paclitaxel solution, removing and drying under vacuum at room temp to give a dry coat wt of about 450 ug. The coating at this point is an amorphous glass. The balloon catheter is placed in a 9 liter glass chamber. The chamber is charged with 16 g of 190 proof ethanol. The surface area of the ethanol in the bottom of the chamber is 176 cm<sup>2</sup>. The catheter is suspended above the ethanol (not in contact with the liquid ethanol). The chamber is then sealed and the vapor annealing process is allowed to proceed for 4-16 hr at room temperature to cause crystallization of paclitaxel. The crystalline form of the drug is paclitaxel dihydrate.

The crystals are fan-like, apparently spherulite, crystals of large size (>100 µm, typically 200-1000 µm diameter). FIG. 1 is exemplary.

##### (b) Small Rod-Like Crystalline Morphology

An uncoated Quantum Maverick balloon (3.0 mm dia.×16 mm length) is placed in a sealed chamber containing saturated ethanol vapor overnight. The balloon is then dip coated as described above (a). The coating at this point is an amorphous glass. The coated balloon catheter is vapor annealed in ethanol as described above (a).

The crystals are rods or needles, often bunched and laid down in star-like or crossing pattern, with much shorter lengths, (10-60 µm length). FIG. 2 is an exemplary surface image, with FIGS. 3a and 3b providing illustrative magnified images depicting the "rod-like" structure of the crystalline particles.

Reference is made to FIGS. 6a-6c, which are SEM images of the surface of a balloon made of Pebax® 7233, depicting the effect of the pretreatment of the balloon surface for 30 minutes, 1 hour and 16 hours respectively. FIG. 6a shows that after 30 minutes ethanol vapor anneal the balloon surface still has no visible topography. However blooming of lauryl lactam is visible in the 1 hour image (FIG. 6b), and is very well developed in the 16 hour image (FIG. 6c).

If a balloon is made of Pebax® 6333, which blooms lauryl lactam without solvent treatment, the rod-like morphology paclitaxel crystals are produced when an amorphous paclitaxel coating is subjected to vapor treatment, even without a vapor anneal pretreatment of the balloon. However, fan-like crystal morphology can be produced on Pebax® 6333 if the balloon is extracted with a solvent that dissolves lauryl lactam, for instance THF, and then the extracted balloon is processed as in Example 1a.

FIG. 4 is an SEM image of a cross-section of a commercial prior art Sequent Please™ balloon catheter, sold by B. Braun, that has a paclitaxel/iopramide coating. The image is taken through the folded balloon and shows small rod-like crystals in the fold area, but they show very poor association

with the surface and seem to have grown to loosely fill void space under the balloon folds, with many crystals extending outward from, rather than parallel to, the surface.

FIG. 5a depicts a cross-section through the fold of a balloon made in a manner of Example 1b above. It can be seen that the crystals of the coating are densely packed, particularly with respect to the plane of the balloon. The coating is thin (substantially under 10  $\mu\text{m}$ ) and is relatively robust due to the high density packing of the crystals parallel to the balloon surface.

FIG. 5b depicts the surface of a balloon made in a manner of Example 1b above.

FIG. 5c depicts the surface of the balloon made in a manner of Example 1b after inflation from the folded state. Note the uniform crystal structure on the surface after inflation from the folded state.

#### Example 2. Deployment in Tube of Large and Small Paclitaxel Crystalline Morphologies

This example illustrates the impact of paclitaxel crystal size on in-vitro performance using the deployment in tube bench-top test. The balloon is folded and deployed in a hydrophilic polyurethane using the following procedure. The tube is placed in water at 37° C. The folded balloon is placed in the tube and inflated after soaking for 1 min. The tube is sized to give 20% overstretch during balloon deployment. Inflation is maintained for 1 minute, vacuum is pulled for 15 sec and the balloon is removed from the tube. The tube is removed from the water and dried and imaged. Images of the deployed drug on the tube are shown in FIGS. 7a and 7b.

Two crystal coating structures were tested. The balloon used to prepare FIG. 7a had large fan-like crystals similar to the balloon depicted in FIG. 1. The balloon used to prepare FIG. 7b had a small rod-like crystalline structure similar to that in FIGS. 3a and 3b.

The balloon with large fan-like crystals transferred correspondingly large particles to the tube (FIG. 7a) compared to smaller drug particles apparent in FIG. 7b. It is considered that the smaller particles of the balloon with the rod-like particles will be safer with respect to coating released systemically in the course of tracking and deployment of these balloons.

#### Example 3. Particulate Testing

Particulate testing was performed on drug coated balloon catheters using the following method. The balloon catheter (N=3 for each design) was tracked through a curved glass artery model and into a hydrophilic polyurethane tube (artificial artery). The artery model is part of a closed loop system in which water flow is maintained during the test (flow rate: 70 ml/min). The flow loop is connected to a laser particle counter. Particle counts are taken while tracking the balloon to the polyurethane artery. Particle counts are taken for 2 min prior to deployment. The balloon is deployed for 30 sec at 12 atm. Particle counts are then taken over a 2 min period post-deployment. Total particle counts for 10-25  $\mu\text{m}$ , 25-50  $\mu\text{m}$  and 50-125  $\mu\text{m}$  particle size bins are measured. Three designs were tested. "Ptx Fan" was a paclitaxel coating (no excipient) with fan-like morphology on a Pebax® 7233 balloon prepared from an amorphous paclitaxel coating by post application vapor annealing of the coating. "Ptx Rod" was a paclitaxel (no excipient) with a rod-like morphology on a Pebax® 7233 balloon prepared by a vapor pre-treatment of the balloon, application of an

amorphous paclitaxel coating and then post-treatment to crystallize the coating. "Sequent Please" was a prior art drug delivery balloon catheter sold by B. Braun with a paclitaxel/iopramide coating. All balloons had paclitaxel drug content of about 3  $\mu\text{g}/\text{mm}^2$ . FIGS. 8a-8c show the particle count results. Of the two paclitaxel particle morphologies, the rod-like morphology gives fewer particles during track/deployment. Both paclitaxel morphologies (rod and fan) give significantly lower particle counts than the commercial comparative control. The result is considered to be indicative that forming a crystalline coating by crystallization of an amorphous coating via vapor annealing gives improved coating properties.

#### Example 4. Ex-Vivo Drug Tissue Levels

Drug coated balloon catheters were deployed (1 min inflation) in explanted porcine arteries under flow conditions at 37° C., 40 ml/min in media (80% Dubecco's Modified Eagle media; 20% Fetal Bovine Serum). Arteries were analyzed for total drug content via LC-MS after 0, 1 and 4 hrs post deployment. The following coating formulations were tested on Pebax® 7233 balloons: paclitaxel crystalline (fan-like); paclitaxel crystalline (rod-like); paclitaxel/acetyl tributyl citrate blend (85/15 wt/wt)—(fan-like); and paclitaxel/acetyl tributyl citrate blend (85/15 wt/wt) (rod-like). Drug content was approximately 3  $\mu\text{g}/\text{mm}^2$  for all formulations. Drug tissue results are shown in FIG. 9.

Both paclitaxel only (rod-like) and paclitaxel/ATBC (rod-like) crystalline morphologies show higher drug tissue levels compared to the corresponding paclitaxel only (fan-like) and paclitaxel/ATBC (fan-like) morphologies. Tissue levels of about 200 to about 600 ng/mg of drug in the tissue. after 4 hours deployment. The samples providing greater than about 300 ng/mg or greater than about 400 ng/mg are considered particularly advantageous.

The preceding examples show that paclitaxel crystal structure (fan & rod) impacts the number of particulates and tissue uptake. The rod like crystalline structure as described in this invention leads to fewer particles and higher tissue levels compared to the comparative commercial balloons taken as controls. Crystalline morphologies generated by vapor annealing have good adhesion to the balloon and good inter-crystal adhesion. Vapor annealing of a continuous integral amorphous drug coating results in solid state (or semi-solid) crystallization of the drug leading to crystalline coatings with the crystals oriented parallel to the balloon surface and robust crystal packing.

The devices of the present invention, may be deployed in vascular passageways, including veins and arteries, for instance coronary arteries, renal arteries, peripheral arteries including illiac arteries, arteries of the neck and cerebral arteries, and may also be advantageously employed in other body structures, including but not limited to arteries, veins, biliary ducts, urethras, fallopian tubes, bronchial tubes, the trachea, the esophagus and the prostate.

In some embodiments a drug coating of paclitaxel on a balloon contains from 100 to 1000  $\mu\text{g}$  of paclitaxel, for instance 200-800  $\mu\text{g}$ , 300-600  $\mu\text{g}$ , or 400-500  $\mu\text{g}$  of paclitaxel. In some embodiments the amount of amorphous paclitaxel on the balloon is from 0-80  $\mu\text{g}$ , less than 60  $\mu\text{g}$ , or less than 30  $\mu\text{g}$ , with the remaining being a crystalline forms. The preceding paclitaxel wts are based on the effective surface area of a 3.0 mm $\times$ 16 mm balloon. For other sizes, adjustments to provide the same weight of drug per unit area may be readily calculated.

In a vapor annealing step with 90-95% ethanol, the water content is sufficient to provide the dihydrate crystalline form within a very rapid time frame, for instance a few minutes. If it is desired to provide anhydrous crystalline paclitaxel a solvent with a lower water content may be used (for example 200 proof ethanol). In some embodiments the amount of anhydrous crystalline paclitaxel on the balloon (3.0 mm×16 mm) is from 0-200 μg, less than 100 μg, or less than 50 μg. In some embodiments the amount of crystalline dihydrate paclitaxel on the balloon is from 50 to 1000 μg, 100-800 μg, 200-600 μg, 300-500 or 350-450 μg. In some embodiments the fraction of amorphous paclitaxel in the coating is from 0-25%, for instance about 1%, about 2%, about 3%, about 5%, about 6%, about 8%, about 10%, about 12%, about 15%, about 18%, about 20%, about 22%, or about 25%, based on total paclitaxel weight. In some embodiments the fraction of anhydrous crystalline paclitaxel is from 0% to about 99%, for instance 1-95%, 5-80%, about 1%, about 2%, about 3%, about 5%, about 6%, about 8%, about 10%, about 15%, about 20%, about 25%, about 30%, about 40%, about 50%, about 60%, about 70%, or about 80%, based on total paclitaxel weight. In some embodiments the fraction of dihydrate crystalline paclitaxel is from 1% to 100%, for instance 1-99%, 5-95%, about 10%, about 15%, about 20%, about 25%, about 30%, about 35%, about 40%, about 45%, about 50%, about 55%, about 60%, about 65%, about 70%, about 75%, about 80%, about 85%, about 88%, about 89%, about 90%, about 91%, about 92%, about 93%, about 94%, about 95%, about 96%, about 97%, about 98%, or about 99%, based on total paclitaxel weight.

All published documents, including all US patent documents, mentioned anywhere in this application are hereby expressly incorporated herein by reference in their entirety. Any copending patent applications, mentioned anywhere in this application are also hereby expressly incorporated herein by reference in their entirety.

The above examples and disclosure are intended to be illustrative and not exhaustive. These examples and description will suggest many variations and alternatives to one of ordinary skill in this art. All these alternatives and variations are intended to be included within the scope of the claims, where the term “comprising” means “including, but not limited to”. Those familiar with the art may recognize other equivalents to the specific embodiments described herein which equivalents are also intended to be encompassed by the claims. Further, the particular features presented in the dependent claims can be combined with each other in other manners within the scope of the invention such that the invention should be recognized as also specifically directed to other embodiments having any other possible combination of the features of the dependent claims. For instance, for purposes of claim publication, any dependent claim which follows should be taken as alternatively written in a multiple dependent form from all claims which possess all antecedents referenced in such dependent claim if such multiple dependent format is an accepted format within the jurisdiction. In jurisdictions where multiple dependent claim formats are restricted, the following dependent claims should each be also taken as alternatively written in each singly dependent claim format which creates a dependency from an antecedent-possessing claim other than the specific claim listed in such dependent claim.

The invention claimed is:

1. A method of making a drug delivery balloon having a coating thereon comprising a drug, the balloon made of a balloon material, the drug selected from the group consisting of paclitaxel, paclitaxel analogs and paclitaxel derivatives,

wherein the drug has a characteristic amorphous form and a crystalline form comprising:

a) applying a coating of the drug in the amorphous form to the balloon material, and, subsequent to applying the coating,

b) annealing with a solvent vapor the coating which has been applied in step a), the solvent vapor comprising an alcohol, to produce the crystalline form of the drug on the balloon,

wherein in the applying step a) the drug coating is applied to a balloon surface that has been nucleated by blooming of a component in the balloon material to the surface thereof, the component crystallizing at the surface of the balloon material as a result of the blooming to induce formation of drug crystals in the annealing step.

2. A method as in claim 1 wherein the coated balloon is annealed in step b) with a solvent vapor.

3. A method as in claim 2 wherein the solvent vapor comprises an alcohol and water.

4. A method as in claim 1 wherein said blooming is facilitated by a pretreatment of the balloon surface prior to applying the drug coating.

5. A method as in claim 4 wherein said pretreatment comprises a solvent vapor annealing of the balloon.

6. A method as in claim 1 wherein the balloon material comprises a polyamide block copolymer.

7. A method as in claim 1 wherein the drug is applied to the device as a formulation with an excipient.

8. Method as in claim 7 wherein said excipient is a member of the group consisting of water soluble polymers, sugars, contrast agents, citrate esters, glycerol esters of short chain monocarboxylic acids and pharmaceutically acceptable salts.

9. A method as in claim 2 wherein in the annealing step the balloon is placed in an annealing chamber in which the solvent vapor, at the time the balloon is put into the chamber, is at a vapor pressure that is less than saturation at the temperature and pressure of the chamber.

10. A method as in claim 2 wherein in the annealing step the solvent vapor is provided in an annealing chamber having a chamber volume to solvent surface ratio in the range of from about 35-75 ml/cm<sup>2</sup>.

11. A method as in claim 1 wherein the balloon surface is nucleated with particulate nucleating agent on the surface of the balloon, said particulate nucleating agent having a major dimension in the size range of from about 10 nm to about 20 μm.

12. A method as in claim 11 wherein the particulate nucleating agent has a density on the balloon of from about 10 particle/mm<sup>2</sup> to about 5000 particles/mm<sup>2</sup>.

13. A method as in claim 11 wherein the particulate nucleating agent has a density on the balloon of from about 100 particles/mm<sup>2</sup> to about 2000 particles/mm<sup>2</sup>.

14. A method as in claim 1 wherein the drug is paclitaxel.

15. A method as in any one of claims 1-3 and 4-6 wherein the drug is applied to the device as a formulation without an excipient.

16. A method as in claim 1 wherein in the applying step a) the nucleation of the balloon surface provides a controlled distribution of drug crystals in the annealing step.

17. A method of making a drug delivery balloon having a coating thereon comprising a drug, the balloon made of a balloon material, the drug selected from the group consisting

of paclitaxel, paclitaxel analogs and paclitaxel derivatives,  
wherein the drug has a characteristic amorphous form and a  
crystalline form comprising:

- a) applying a coating of the drug in the amorphous form  
to the balloon material, and, subsequent to applying the 5  
coating,
- b) annealing with a solvent vapor the coating which has  
been applied in step a), the solvent vapor comprising an  
alcohol, to produce the crystalline form of the drug on  
the balloon, 10

wherein in the applying step the drug coating is applied to  
a balloon surface that has been nucleated by treating the  
balloon material so as to cause a component from  
within the balloon material to migrate to the surface of  
the balloon material, the component crystallizing at the 15  
surface of the balloon material and inducing formation  
of drug crystals in the annealing step.

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